THE NICKEL BULLETIN

A SUMMARY OF CURRENT INFORMATION ON NICKEL

JUNE, 1953

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CASTINGS IN ALLOYS OF NICKEL-MOLYBDENUM-IRON, NICKEL-MOLYBDENUM-CHROMIUM-IRON AND NICKEL-SILICON *page* 90

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CASTINGS IN ALLOYS OF NICKEL-MOLYBDENUM-IRON, NICKEL-MOLYBDENUM-CHROMIUM-IRON AND NICKEL-SILICON

The most important alloys in this group, from the industrial point of view, are the nickel-base alloys known as Hastelloy[1] A, B, C and D, developed in the United States by the Haynes Stellite Division of Union Carbide and Carbon Corporation, where they are widely used to withstand abnormally severe corrosion conditions such as arise in handling mineral acids and strong oxidizing agents.

British requirements for these materials have, in the past, been met by importation from America. The present economic situation has, however, stimulated efforts to develop production facilities on this side of the Atlantic, and castings in alloys of similar type, such as Corrosist[2] B, C, D, and Langalloy[3] 4R, 5R, 6R, are now readily available in the United Kingdom. Castings equivalent to Hastelloy A are not produced in Great Britain as it has been found that one or other of the alloys B, C or D will meet the majority of industrial requirements.

The approximate composition and properties of castings in the alloys under review are shown in the attached Table. In order to obtain maximum toughness, machinability and corrosion-resistance, the following annealing treatments are recommended:—

Castings in Alloy B

Heat at 1150° to 1180°C. for 1 to 2 hours, according to mass and section of casting, and cool rapidly in air.

Alloy C

Heat at 1205° to 1220°C. for 1 to 2 hours, according to mass and section of casting, and cool rapidly in air.

Alloy D

Heat at 970° to 1000°C. for 3 hours and cool slowly in furnace.

Castings in alloy D are hard and relatively brittle, and where maximum toughness is desired the silicon content should be maintained at the lower limit of approximately 7·5 to 8·5 per cent.

Welding of cast parts is usually conducted by the atomic hydrogen, Heliarc, or oxy-acetylene processes. Preheating is often necessary when welding castings of medium and large size. The oxy-acetylene process is always employed for welding alloy D.

Castings in alloys of the Hastelloy type are principally employed in chemical engineering, and in oil-refining, for such parts as valves, pumps, pipe connections, etc., in view of their good resistance to corrosion by acids. They are practically immune from corrosive attack under exposure to normal atmosphere, fresh or salt water, and neutral or alkaline salts. A brief guide to the corrosion resistance of these alloys is as follows:—

Hastelloy B

Particularly well suited for equipment handling aerated and unaerated hydrochloric acid at all concentrations and temperatures up to boiling point. Even in the presence of an abundant supply of oxygen corrosion rates seldom exceed 0·04 in. per year. It has good resistance to hot phosphoric acid solutions.

Hastelloy C

Specially resistant to strong oxidising agents, such as nitric acid, and may also be used in contact with free chlorine, aqueous solutions containing chlorine or hypochlorites, and acid solutions of ferric or cupric salts. It is resistant to attack by hydrochloric acid at room temperature and is, in fact, slightly superior to Hastelloy B for handling cold solutions containing less than 5 per cent. of this acid. Hastelloy C is also highly resistant to acetic, formic, phosphoric and sulphurous acids and has excellent resistance to mixtures of zinc and ammonium chlorides, as used in dry battery filling machines. In cold solutions of phosphoric acid corrosion rates on laboratory test are invariably below 0·0001 in. per year.

Hastelloy D

Hastelloy D is exceptionally resistant to sulphuric acid of all concentrations, even up to boiling point, and alloys of this type have found their widest application in equipment employed in the concentration of sulphuric acid, e.g., heater tubes, valves, pipes, etc. The alloy is practically unaffected by acetic or formic acid, and it has a low corrosion rate in phosphoric acid. It is not resistant to strong oxidizing agents.

(1) Registered trade-mark of Haynes Stellite Division of Union Carbide and Carbon Corporation.

(2) Registered trade-mark of Sheepbridge Engineering Co. Ltd.

(3) Registered trade-mark of Langley Alloys Limited.

Approximate Composition and Properties of Alloys of the Hastelloy Type in the As-Cast Condition

		B	C	D
Composition, *per cent.*	Nickel ..	60-67	51-61	81-85
	Molybdenum	26-30	16-18	—
	Iron ..	4-7	4-7	1 max.
	Chromium	1 max.	15-17	1 max.
	Tungsten ..	—	3·75-4·75	—
	Silicon ..	1 max.	1 max.	7·5-10·0
	Manganese	1 max.	1 max.	0·75-1·25
	Copper	—	—	3-4
	Carbon ..	0·12 max.	0·15 max.	0·12 max.
Physical Properties				
Specific gravity		9·24	8·94	7·8
Weight, *lb.per cu. in.*		0·330	0·320	0·280
Melting range, *deg. C.*		1320-1350	1270-1300	1110-1120
Mean Specific Heat		0·091	0·092	0·11
Mean Coefficient of Expansion, *millionths per °C.*				
0-100°C.		10·0	11·0	11·0
0-1000°C.		14·6	15·3	18·1
Thermal Conductivity, *c.g.s. units* 0-100°C.		0·03	0·03	0·05
Electrical Resistivity, *microhms/cm./sq. cm. at* 24°C.		135·0	133·0	113·0
Electrical Conductivity, *per cent. of copper at* 24°C.		1·31	1·33	1·56
Magnetic Properties		Slightly magnetic (Permeability about 4)	Slightly magnetic (Permeability about 4)	Non-magnetic
Pattern Shrinkage, *in./ft.*		0·25	0·25	0·25
Mechanical Properties				
Yield Point, *tons/sq. in.* (0·2% *Ext.*) ..		23-25	23-25	22-25
Maximum Stress, *tons/sq. in.*		32-36	31-35	22-25
Elongation, *per cent. on* 2 *in.*		5-10	5-10	0-1
Reduction of Area, *per cent.*		13-19	9-13	0-1
Hardness, *Brinell*		200-250	180-220	400-500
Hardness, *Rockwell B*		90-99	89-97	—
Hardness, *Rockwell C*		—	—	30-50
Impact, Izod, *ft.-lb.*		10-15	8-12	0-2
Elastic Modulus in Tension *millions of lb./sq. in.*		28	28	28

ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

NICKEL

Production of Nickel Sponge (Raney-Type) Catalyst

'New Unit for Sponge Nickel.' *Steel*, 1953, vol. 132, Mar. 30, pp. 114, 116.

This note reports installation of plant, at the works of The Davis Chemical Corporation, Baltimore, for production of nickel catalyst, by leaching of a 50-50 nickel-aluminium alloy. The process used is similar to that employed in production of the Raney catalyst, but since the trademark 'Raney nickel' is owned by the Raney Catalyst Company, Chattanooga, Tenn., the product of the Davis Company is being marketed under the name of 'sponge nickel'. The main features of manufacture of the catalyst are briefly described.

Saturation Magnetization of Nickel at High Pressure

G. O. JONES and F. D. STACEY: 'The Saturation Magnetization of Nickel at High Pressure.' *Proc. Physical Soc.*, Sect. B, 1953, vol. 66, Mar. 1, pp. 255-6.

Report of investigation of magnetic properties under high pressures in high fields. Brief notes are given on testing technique, and the results are summarized in a curve representing the reversible behaviour of work-hardened nickel. A full report of the work is to be published later.

Nickel in Magnetostrictive Sonic Delay Line

H. EPSTEIN and O. STRAM: 'Magnetostrictive Sonic Delay Line.' *Rev. Scientific Instruments*, 1953, vol. 24, Mar., pp. 231-2.

The purpose of the investigation described in this note is primarily to develop a storage system for a low-speed digital computer, as well as the application of the device as a continuously variable delay line, as a pulse distributor, for serial to parallel conversion, and in multiplying devices. To date of the report the work has resulted in development of a laboratory test model and prototype models of a recirculating memory unit with a storage capacity of 125 bits at a 450 kc repetition rate, and a four-channel pulse distributor. In the laboratory test model the delay element is a three-foot piece of thin-walled nickel tubing, 0·045 in. o.d. Arguments in favour of the use of tubing in preference to ribbon are advanced. The authors urge the advantages of a magnetostrictive sonic delay line of the type described, for applications in which extremely great resolution is not required. The work reported was carried out in the laboratories of Burroughs Adding Machine Company, Research Division, Philadelphia, Pa.

Spectrochemical Analysis of Nickel

W. NIELSCH: 'Contribution to the Study of the Spectrochemical Analysis of Nickel.' *Metall*, 1953, vol. 7, Apr., pp. 260-1.

The method described makes possible determination, in nickel, of the following elements, in the range 0·01-1 per cent., with an accuracy of $\pm 6 \cdot 5$ per cent.: cobalt, manganese, iron, magnesium, copper. The following impurities can also be simultaneously estimated: lead, tin, zinc, silver. Special procedure essential for estimation of silicon is detailed.

ELECTRODEPOSITION AND OTHER COATING METHODS

'Substitute' Finishes vis-à-vis Electrodeposited Nickel Coatings

M. CERESA: 'A Critical Review of Substitute Finishes.' *Amer. Electroplaters' Soc., Proc. 39th Annual Convention*, 1952, pp. 181-97.

This review of the situation relates primarily to American conditions, but the conclusions drawn are broadly applicable also to those obtaining in other countries.

The author lists the criteria by which a 'substitute' coating must be evaluated:

Appearance: comparable to that of the finish which it is replacing, with retention of such appearance for a reasonable period.

Corrosion-Resistance: comparable to that of the finish formerly used.

Cost: approximately the same as that of the finish formerly used.

Equipment: in a short-term programme of 'substitute' finishes it is essential that, so far as possible, existing equipment should be used, and requirements for new plant be kept to a minimum. Requirements for manpower to instruct on 'know-how' of new processes should also be kept down.

The current availability of plating metals, at the time of writing, is discussed, in relation to statistics on the amounts of nickel used in U.S.A. for plating in the years 1946-1949.

Finishes for present and possible future use are then considered, in the following categories:—

A. *Finishes in Extensive Use*

1. Nickel + chromium.
2. Copper + nickel + chromium.
3. Copper + flash nickel + chromium.
4. Copper + chromium.
5. Copper + chromium + clear baked enamel.

B. Finishes in Moderate Use

1. Bright zinc.
2. Bright zinc + clear chromate dip.
3. Bright zinc + clear chromate dip + clear baked enamel.
4. Bright zinc + chromium.
5. Bright zinc + chromium + clear baked enamel.
6. White brass (zinc 80%-copper 20%).
7. White brass + clear lacquer.
8. White brass + chromium.
9. White brass + chromium + clear baked enamel.
10. Copper + white brass + chromium.

C. Finishes for Possible Future Use

1. Copper + Albaloy (copper 55%-tin 25%-zinc 20%).
2. Copper + Albaloy + nickel flash + chromium.
3. Speculum (copper 60%-tin 40%) + chromium.
4. Nickelex (copper 90%-tin 10%) + chromium.
5. Tin-nickel alloy (tin 65%-nickel 35%).
6. Tin-antimony alloy (tin 55%-antimony 45%).
7. Chromium.
8. Antimony.
9. Nickel-iron alloy (nickel 70%-iron 30%).
10. Composite coatings (nickel + copper + nickel + chromium).

After a critical discussion of the advantages and the limitations of the above types of coating, a tabular summary is made of decorative and protective finishes used on various parts (*a*) in 1949, and (*b*) in 1952. The fields covered include food-service and other domestic equipment, miscellaneous industrial appliances, cooler and X-ray equipment, hardware, automobile parts. The general behaviour of substitute finishes in the respective applications is described, on the basis of experience during the emergency period.

The general conclusion, from a critical evaluation of information available, is summarized by the author as follows:—

'At present it is the general opinion that a good substitute has not been found for nickel for outdoor or similar corrosive exposure. Substitute finishes such as copper-chromium, zinc-chromium, and white brass-chromium are being used and found suitable for many purposes. The copper-chromium finish appears to be the most widely used substitute. The addition of baked clear enamels to the substitute or alternate finishes makes them usable for out-of-doors or similar corrosive conditions where nickel is not permissible. The nickel-tin and copper-tin alloys show promise as substitutes for nickel. Additional work must be done to improve the substitutes being used or those contemplated for future use.'

Electroplating of Magnesium

H. K. DELONG: 'Electroplating on Magnesium.' *Bull. Inst. Metal Finishing*, 1953, vol. 3, No. 1, pp. 29-48. Advance copy of paper presented at Spring Conference of the Institute of Metal Finishing, April, 1953.

The author describes, in detail, a plating process which, after thorough laboratory and pilot-plant trials, is now in large-scale operation. Essentially the process is based on initial deposition (on a suitably prepared magnesium surface) of a thin coating of zinc, applied by chemical reduction. The bath first used contained (g./L.) sodium pyrophosphate 120, zinc sulphate 30, but further research has indicated that a more concentrated bath is less critical to operate and less sensitive to the varying composition of the magnesium-base materials which are treated. The solution now most generally used is an aqueous one of the following composition :—

	g./L.
Zinc sulphate monohydrate ($ZnSO_4.H_2O$) ..	45
Tetrasodium pyrophosphate ($Na_4P_2O_7$)	210
Potassium fluoride (KF)	7
or	
Sodium fluoride (NaF)	5
Sodium carbonate (Na_2CO_3)	5

The bath is operated at 175°-185°F. (80°-85°C.) and is mildly agitated, to prevent stratification. Time of treatment is 3-10 minutes, according to composition of alloy treated, temperature and freshness of bath, method of surface preparation, etc. The time of immersion should be no longer than is required for complete coverage with a continuous coating of zinc; excessive prolongation of treatment may result in less adherent deposits. The normal zinc coating is approximately 0·0001 in. thick.

It is emphasized by the author that, prior to the zinc-immersion treatment, correct surface conditioning and activation are essential. Particulars are given of pickling solutions suitable for various classes of magnesium-base material and of the activating treatment, which is carried out in a bath containing phosphoric acid with sodium, potassium, or ammonium acid fluoride.

Following the zinc-coating process (i.e., the third step), a flash of copper is deposited from an alkaline-cyanide type of bath: typical compositions are given. The thickness of this initial copper coating is determined by the nature of the bath which is to be used for completion of the copper plating. Once an adequate thickness of copper has been deposited (preferably at least 0·0003 in.), nickel may be applied from any of the conventional baths. For plating of tubing, deeply recessed parts, or other areas which may have an inadequate coverage of copper, a nickel bath which does not seriously attack magnesium has been developed: its composition and operating conditions are shown below:—

	g./L.
Nickel sulphate ($NiSO_4.6H_2O$)	60
Boric acid (H_3BO_3)	35
Ammonium fluoride (NH_4F)	
or	
Ammonium acid fluoride (NH_4HF_2)	50
Wetting agent	0·5
Hydrofluoric acid (HF)	When required, to reduce pH to 5.5
Operating temperature	115-125°F. (45°-52°C.)
Current density	5-15 amp./sq. ft.

Chromium may be subsequently deposited from any of the standard baths (over the copper-nickel undercoat for decorative purposes, or immediately after the copper-strike treatment, in cases where high wear-resistance is required). Other types of metal too may be deposited after completion of the copper-plating cycle. The process embodying the zinc-immersion pre-treatment is also applicable for barrel plating of magnesium-base materials.

The author discusses the properties of magnesium alloys electroplated by the method recommended.

Adhesion obtained by correct treatment is equivalent to that of coatings obtained on zinc-base die-castings, and the coatings do not peel on exposure to moderately elevated temperatures. Extensive investigation of electrodeposits, in various types of accelerated and normal corrosive environments, indicates that, in general, coatings on magnesium made by the approved methods give a good degree of corrosion- and tarnish-resistance, equal to that of coatings deposited on aluminium- and zinc-base materials. The author quotes results of comparative tests made, at various sites, by a large automobile company in U.S.A.

Economic Maintenance of Nickel-Plating Solutions

'Small Plating Plants; How to Save Nickel Solution.' *Iron Age*, 1953, vol. 171, Apr. 16, p. 117.

Describes, with schematic diagram, method of pumping introduced in General Motors Corporation plating plant at Pontiac, in connexion with purification and re-circulation of solutions. The procedure described is claimed to effect, in this plant, a monthly saving of some 1200 gallons of nickel-plating solution. In addition, the conservation has helped to solve problems of stream pollution arising from discharge of plating waste.

Black Nickel Plating

E. J. SERFASS, R. F. MURACA and W. R. MEYER: 'An Explanation of Black Nickel Plating.' *Amer. Electroplaters' Soc., Proc.* 39*th Annual Convention*, 1952, pp. 101-9; disc., pp. 109-11.

The authors present an explanation of the mechanism of black-nickel plating, as well as of immersion blackening of zinc, iron, and other metals in solutions containing thiocyanate and thiosulphate. Thermodynamic calculations are given to indicate that thiocyanate and thiosulphate ions are reduced to sulphide ions, either electrically or by dissolution of metal. The mechanism of the reaction, and the reason for the use of zinc ions and ammonia, are discussed.

NON-FERROUS ALLOYS

Copper-Nickel-Tin Alloys: Properties and Uses

J. W. CUTHBERTSON: 'Copper-Nickel-Tin Coining and Stamping Alloys.' *Metal Industry*, 1953, vol. 82, Apr. 17, pp. 301-3.

The work reported in this paper was carried out to determine the feasibility of using tin as a partial substitute for nickel in alloys required to show good strength, ductility, and workability, combined with a colour approximately similar to that of copper-nickel alloys containing 25-30 per cent. of nickel. The binary 75-25 copper-nickel alloy is popular for stamping and embossing operations, and in this investigation its properties were taken as the standard criterion for assessing the adequacy of the copper-nickel-tin alloys.

Initially alloys containing 20 per cent. of nickel with 5, 6 or 8 per cent. of tin were prepared, but it was found that the 6 and 8 per cent. tin alloys could not be softened sufficiently to enable them to compete with the 75-25 cupro-nickel. Work was therefore concentrated on the alloy containing 5 per cent. of tin. Tests on this alloy, in various conditions, indicated that the maximum amount of tin which could be tolerated in a 20 per cent. nickel alloy for embossing was 5 per cent. Weight for weight, tin exerts a greater hardening effect than nickel, and the 20-5 nickel-tin-copper alloy only just met softness requirements. Preliminary experiments with a 15 per cent. nickel grade again showed 5 per cent. of tin to be the maximum permissible in production of soft blanks. Effects of mechanical and thermal treatments on the 5 per cent. tin, 15 per cent. nickel series showed that the properties obtainable were not significantly different from those of the 20 per cent. nickel, 5 per cent. tin alloys; the hardness, although low enough to permit coining, was 10 points (Vickers Diamond Hardness) above the value generally preferred in material used for this purpose. The effect of reducing the tin content of the 15 per cent. nickel alloy to 3 per cent. was therefore examined. This modification enabled a substantial reduction in hardness to be made, and satisfactory embossing qualities were obtained, but the lower tin content was associated with some deterioration in the colour, which was slightly yellow.

It is concluded that neither the 15-5 nor the 15-3 nickel-tin-copper alloy is a perfect substitute for the 75-25 copper-nickel alloy, but that (1) for applications in which a slightly greater hardness after annealing could be tolerated the 5 per cent. tin modification might be acceptable, and (2) where some departure from the whiteness of the 75-25 copper-nickel could be permitted the 3 per cent. tin, 15 per cent. nickel alloy merits consideration.

It is noted that no significant metallurgical difficulties were experienced in casting, rolling and annealing the ternary alloys, which behaved in a manner very similar to that of the binary copper-nickel, but tended to work-harden rather more rapidly.

Precipitation-Hardening Copper-Nickel Alloy

'New Copper Alloy.' *Steel*, 1953, vol. 132, Mar. 30, p. 88.

At the Western Metals Congress held by the American Society for Metals in March last a paper by D. B. ROACH and colleagues described work at Battelle Memorial Institute which has resulted in development of a new age-hardenable copper-base alloy containing about 10 per cent. nickel, 1·5 per cent. silicon, 4 per cent. aluminium. In the age-hardened condition the alloy gives the following properties:—

Yield Strength	120,000 p.s.i. (53·5 t.s.i.)
Tensile Strength ..	140,000 p.s.i. (62·5 t.s.i.)
Elongation	8 per cent.
Limit of Proportionality	85,000 p.s.i. (38 t.s.i.)
Modulus of Elasticity ..	19 million p.s.i.
Electrical Conductivity	11 per cent. that of copper

By application of 15 per cent. of cold work the mechanical properties can be still further raised, to

the values shown below:—

Yield Strength	129,000 p.s.i. (57·5 t.s.i.)
Tensile Strength ..	143,000 p.s.i. (64 t.s.i.)
Elongation	5 per cent.
Limit of Proportionality	104,000 p.s.i. (46·5 t.s.i.)

The alloy is being considered for the production of spring contacts to be used in various types of business machine.

Nickel-Aluminium Bronze Marine Propellers

'Cast Nickel-Aluminium Bronze Makes Good Marine Propellers.' *Nickel Topics*, 1953, vol. 6, No. 3, pp. 1, 3.

This article records the placing of a large order for adjustable-pitch propellers for U.S. Navy minesweepers and landing craft. The approximate composition of the alloy used, and the specification to which it is supplied, are shown below:

Nickel 5, iron 4, aluminium 10, per cent., with or without manganese, balance copper.

	As-cast		Heat-treated	
	p.s.i.	t.s.i.	p.s.i.	t.s.i.
Tensile Strength, min.	90,000	40	110,000	49
Yield Strength, min.	40,000	18	60,000	26·5
Elongation, min.	10%		5%	

(These properties fall within the limits of A.S.T.M. Specification B 148-49-9D and MIL-B-16033, Class 4)

Bronzes of this type are tough, workable, and readily welded and brazed, and tests made at the Kure Beach Corrosion Testing Station and elsewhere show that the cavitation-erosion resistance of such alloys is definitely superior to that of manganese bronze, tin bronze, and red brass. The propellers described in this article are installed as-cast, but the nickel-aluminium bronzes are usefully susceptible to strengthening by heat-treatment (see table above) and, where design permits, castings are frequently used in the quenched-and-tempered condition. In addition to their advantages for propellers, nickel-aluminium bronze alloy castings are being successfully employed for ordnance parts, marine pumps, aircraft bushings, steel-rolling-mill parts, and equipment used in the power, electrical, glass and chemical-process industries. The useful degree of mechanical strength retained at temperatures up to 750°F. (400°C.) makes nickel-aluminium bronze suitable for service in steam plants and other applications involving resistance to moderately elevated temperatures.

Nickel-containing Materials in Non-Magnetic Ships

See abstract on p. 103.

Identification of Alloys and Stainless Steels

See abstract on p. 103.

Spectroscopic Analysis of Steel and Non-Ferrous Alloys

K. D. MIELENZ: 'Rapid Analysis of Steels, and Aluminium- and Copper-base Alloys, using the Metal Spectroscope.' *Metall*, 1953, vol. 7, Apr., pp. 256-60.

The first part of the paper comprises a description of a spectroscope developed in Germany for use in routine analysis. Analytical procedure is exemplified by reference to determinations of various elements in steel, and in aluminium- and copper-base alloys. The information given includes a table relating to estimation of nickel in copper.

NICKEL-IRON ALLOYS

Order-Disorder Transformation in Iron-Nickel Alloys in the $FeNi_3$ Region

R. J. WAKELIN and E. L. YATES: 'A Study of the Order-Disorder Transformation in Iron-Nickel Alloys in the Region $FeNi_3$.' *Proc. Physical Soc.*, Sect. B, 1953, vol. 66, Mar., pp. 221-40.

Order-disorder transformation in iron-nickel alloys of high purity was studied by means of measurements of electrical resistivity, X-ray analysis, and examination of the magnetic properties of the alloys in both low and high magnetic fields. Some 50 alloys were used in the investigation, ranging in composition from 45 to 85 at.-per cent. nickel and including a series having the $FeNi_3$ composition plus small percentages of aluminium, molybdenum, copper and manganese. Each alloy was hot forged and afterwards homogenized at 1200°C., as this treatment had been found to ensure uniform composition throughout the mass.

Correlation of the data obtained by the various methods of examination indicates that the order-disorder transformation takes place over a wide range of composition, from about 50 to 80 at.-per cent. nickel. A maximum change in structure-sensitive properties is observed at 75 at.-per cent. of nickel.

The formation of order is extremely sluggish: it takes place in the range 494°-500°C. The decrease in lattice parameter of the 75 per cent. nickel alloy which occurs on formation of the ordered structure is 2×10^{-3}Å. The existence of the superlattice was confirmed and, using the counter-spectrometer technique, an estimate of the degree of order was obtained. Magnetic measurements in low fields show that the maximum-permeability and initial-permeability values of $FeNi_3$ are considerably lowered by the annealing process known to produce the ordered condition in the alloy. Coercive force is increased by such treatment. Results obtained in the study of the effects of small additions of the third elements mentioned support the assumption that the 'spare' electrons of the added elements enter the 3d shell of the nickel atoms only, leaving unaltered the contribution of the iron atoms to the total magnetic moment. The iron and nickel atoms may thus be considered to act independently.

Nickel-containing Permanent-Magnet Alloys: Microradiographic Studies

H. J. GOLDSCHMIDT: 'Microradiography of Permanent-Magnet Alloys.' *Metallurgia*, 1953, vol. 47, Apr., pp. 215-20.

The technique of X-ray microradiography is already being usefully applied in several fields of metallurgy and mineralogy, for the study of the segregation of elements in certain areas of a matrix. In permanent-

Co %	Ni %	Cu %	Al %	Nb %	Ti %	Mn %	C %	Fe %
21·3	11·6	4·6	8·58	—	—	—	0·04	remainder
24·8	13·3	4·2	8·35	0·72	—	0·06	0·03	"

magnet alloys, particularly the Alnico and anisotropic Alcomax types, the presence or absence of such segregations is of special interest, in that they may influence the magnetic properties to a significant extent. This paper reports some observations made on two Alcomax alloys, the compositions of which were as in the Table above.

The specimens were examined (*a*) as cast, and after a variety of heat-treatments, i.e., (*b*) as hardened; (*c*) as hardened and tempered; (*d*) as hardened with an external magnetic field applied during cooling; (*e*) as (*d*), but followed by tempering. Radiographic data on the alloys in each condition are given in the paper. The nature of the segregates found, and the occurrence of cracking along the grain boundaries are discussed in detail, with many illustrations.

The five types of segregate found varied in character from crystal to crystal and were influenced by heat-treatment. They can all be explained in terms of the phase constitution and precipitation effects known to occur in these alloys. The distribution of the segregates is likely to have a fundamental bearing on the magnetic properties of the alloy, so that the effect of such external measures as the application of a magnetic field during cooling, or the growth of columnar crystals from the melt, will partly consist in controlling and modifying the segregates and their degree of anisotropy. It is suggested that detailed study of the relationship between the segregates and the magnetic properties, composition, and heat-treatment of this type of alloy would be fruitful.

It is also shown that crack formation in these (and other) alloys can be usefully studied by microradiographic technique. X-rays give a stereoscopic view, revealing cracks at successive depths below the surface, as well as indicating their width and angle. The cracks tend to be intercrystalline, and to be related in direction to the intracrystalline segregates.

Effects of Macrostructure on Properties of Nickel-containing Permanent-Magnet Alloys

D. G. EBELING and A. A. BURR: ' Effects of Macrostructure on the Performance of Alnico Permanent Magnets.' *Jnl. of Metals*, 1953, vol. 5, Apr., *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 537-44; T.P. 3433E.

The authors open with a highly condensed but informative summary of the main literature dealing with the development of nickel-aluminium-iron-base magnet alloys. They then describe work carried out to develop a method for improving the properties of anisotropic Alnico 5 magnets, carried out as a result of observations that the magnetic quality of such materials is affected by the as-cast macrostructure. Single-crystal specimens of the nominal composition aluminium 8, nickel 14, cobalt 24, copper 3, iron 51, per cent. were produced by special sintering and grain-coarsening techniques, to permit study of the effect of crystal orientation. From the detailed data recorded the following conclusions are drawn:—

'Massive crystals of Alnico alloys can be produced either by slow sintering of fine, non-oxidized powders or by the coarsening of relatively fine-grained castings.

'The results obtained on single-crystal specimens show that the orientation of the magnetic axis has a marked effect on the performance of Alnico permanent magnets. The squarest demagnetization curves and the highest coercive force and maximum energy values are obtained in the cube direction, while the octagonal direction is the lowest in these respects. With a [100] magnetic axis, the maximum energy of sintered Alnico 5 crystals was about 6,000,000 gauss-oersted, which is appreciably greater than the [111] orientation value of 3,500,000 gauss-oersted. Cast Alnico 6 crystals under similar circumstances gave values of 6,500,000 and 2,900,000 gauss-oersted.

'An analysis of the results obtained on single-crystal and polycrystalline specimens indicates that the maximum energy value is reduced by a refinement in the grain size.

'Cube textures are developed in castings of these alloys, and desired orientations of this texture can be realized by the controlled extraction of the heat of solidification. A cast texture in which the columnar grains are aligned parallel to the magnetic axis will produce significantly higher maximum energies than the normal, randomly oriented, grain structure. These pronounced orientation effects can be explained partially on the basis of a cube texture coupled with the pronounced magnetic anisotropy, and partially as the result of a larger effective grain size as measured in the direction of the magnetic axis.

'A cube-oriented, cast Alnico 5 crystal produced an energy value in excess of 7,500,000 gauss-oersted.'

Alnico Permanent Magnets: Production, Properties, Uses

E. E. GEORGE: 'Permanent Magnets Attract More Industry Attention.' *Steel*, 1953, vol. 132, Apr. 20, pp. 110-13.

This is a semi-popular article based on production practice at the plant of General Electric Company, Detroit, where eight grades of Alnico-type magnet are now being made. All grades can be made in cast form, and grades 2, 4 and 5 are also being produced commercially by powder-metallurgy methods.

The writer emphasizes the following points: the

importance of correct design as a means of making the fullest use of the properties of the Alnico alloys; precautions necessary to prevent demagnetization by heat, vibration, impact, stray magnetic fields, or other external influence; the wide range of applications for which Alnico-type magnets are suitable, and some of the factors which must be considered in using them in individual types of equipment.

CONSTRUCTIONAL STEELS

Temper-Brittleness in High-Purity Iron Alloys

A. PREECE and R. D. CARTER: 'Temper-Brittleness in High-Purity Iron-base Alloys.'
Jnl. Iron and Steel Inst., 1953, vol. 173, Apr., pp. 387-98. See also *Iron and Steel*, 1953, vol. 26, May 14, pp. 257-61; disc., pp. 291-4.

The majority of investigations on temper-brittleness have been made on commercial steels and modifications of such steels. In view of the limitations of such materials, due to the presence of numerous elements, it was considered desirable to study the phenomenon of temper-brittleness in simple iron-base alloys of high purity, in order to determine the elements responsible for temper-brittleness, and their individual characteristics in relation to the embrittling process. The work now reported was done under the aegis of the British Iron and Steel Research Association.

In the first series of alloys examined compositions were selected to reveal the relative importance of chromium, manganese, nickel and phosphorus, singly and in combination. The compositions chosen for the second series contained various proportions of chromium + phosphorus, and were designed to demonstrate the minimum concentration of chromium which will induce susceptibility to temper-brittleness in the presence of phosphorus. The specimens were carburized to 0·1 per cent. carbon. Alloys in the third series were chosen to confirm earlier results which had suggested that the presence of phosphorus might be essential for the development of temper-brittleness, and also for the purpose of examining the influence of molybdenum and arsenic. These alloys were carburized to 0·2 per cent. carbon. A fourth series was representative of alloys known to be highly susceptible to temper-brittleness; these were examined to determine the influence of manganese, chromium, nickel and phosphorus, on the kinetics of the temper-embrittling process. In this group also the alloys were carburized to about 0·2 per cent. carbon.

The influence of the respective elements was assessed by microscopical examination and by determination of transition temperature after embrittling treatments. The following summary is given of the observations made:—

'Temper-embrittlement involves a change at the ferritic grain boundaries (and sub-boundaries) of susceptible materials. The location of the embrittling change is independent of any prior γ-iron (austenitic) structure. The region involved in the change appears to be less than 1000Å in thickness, and possibly less than 100Å, and it suffers a decrease in cohesive strength. The grain-boundary change may lead to an intercrystalline brittle fracture and a corresponding rise in transition temperature in the impact test, although the embrittling change can proceed slightly before the fall in intergranular cohesion is sufficient for an intercrystalline brittle fracture.

'Temper-brittleness has not been detected in a pure iron-carbon or iron-phosphorus-carbon alloy, but it occurs to a marked extent in iron-base alloys containing chromium or manganese, together with phosphorus and carbon. It also occurs slightly in almost phosphorus-free (<0·001%) alloys containing high manganese or high chromium, and carbon.

'Temper-brittleness may be detected by the etch test in iron-chromium-phosphorus-carbon alloys containing as little as 0·4 per cent. of chromium and 0·014 per cent. of phosphorus, but in such alloys (containing no manganese) about 0·8 per cent. of chromium has to be present before the embrittling change leads to intercrystalline brittle fracture and a rise in transition temperature.

'On the basis of either weight or atomic percentage, the embrittling effect of manganese is appreciably greater than that of chromium.

'There is little difference in the kinetics of the embrittling process between susceptible manganese-containing and chromium-containing alloys, apart from a somewhat more rapid approach to equilibrium at higher embrittling temperatures with the latter.

'Temper-brittleness was not detected in phosphorus-free iron-nickel-carbon alloys containing up to 4 per cent. of nickel, nor in an iron-carbon (0·1% carbon) alloy containing 0·04 per cent. of phosphorus and 1·5 per cent. of nickel.

'The addition of nickel to susceptible iron-manganese-phosphorus-carbon and iron-chromium-phosphorus-carbon alloys does not appear to affect the fall in intergranular cohesion on embrittlement, though it may make temper-brittleness more apparent in the impact test.

'The addition of about 0·5 per cent. of molybdenum to susceptible manganese- or chromium-containing alloys almost completely suppresses the embrittling change, its effect being to greatly decrease the equilibrium extent of embrittlement, rather than the rate at which equilibrium is attained.

'Reducing the carbon content of a susceptible alloy at first has little effect upon the development of the embrittling change, although the altered mechanical properties of the base material tend to make the alloy appear less susceptible in the impact test. With carbon reduced to about 0·003 per cent. susceptibility disappears.

'The presence of arsenic in a phosphorus-free iron-chromium-carbon alloy produces marked susceptibility.

'The development of the embrittling change may be detected in susceptible chromium-containing alloys by aqueous or alcoholic picric-acid etchants, and the addition of surface-active reagents increases the sensitivity of such etchants. Although the embrittling change occurs with almost identical characteristics in manganese-containing alloys, it cannot be detected by these same etchants in the absence of chromium.'

Influence of Arsenic and Antimony on Temper-Brittleness

G. W. AUSTIN, A. R. ENTWISLE and G. C. SMITH: 'Effect of Arsenic and Antimony on Temper-Brittleness.' *Jnl. Iron and Steel Inst.*, 1953, vol. 173, Apr., pp. 376-86. See also *Iron and Steel*, 1953, vol. 26, May 14, pp. 261-4; disc., pp. 291-4.

Both arsenic and antimony are usually present in small amounts in steels. In eight low-alloy steels used at the National Physical Laboratory the percentage (by weight) of arsenic was found to vary over the range 0·023-0·039 per cent. (values comparable with those relating to phosphorus in the same steels). Examination of twenty-one steels by some American investigators showed an average of 0·01 per cent. arsenic with a maximum of 0·034 per cent. The only figures available for antimony content (from the same series of American steels) were average 0·01 per cent., maximum 0·028 per cent.

In view of the known embrittling influence of these two elements on carbon and certain alloy steels, it was thought desirable to establish their effect on temper-brittleness of low-alloy steels.

Two types of steel were used for the investigation: En 23 (3 per cent. nickel nickel-chromium steel containing carbon 0·25-0·35 per cent.) and En 23+ small amounts of molybdenum. Each type was made up with (*a*) four different arsenic contents, or (*b*) two different antimony contents.

The treatments given to the steels were as follows:—

(1) *Arsenic-containing En* 23: oil-quenched after 1 hour at 900°C.; tempered at 620°C. for 1 hour. Some specimens of each batch were then embrittled at 525°C. for 4 hours and some for 8 hours.

(2) *Arsenic-containing En 23+Mo:* oil-quenched after 1 hour at 900°C: tempered at 650°C. for 2 hours. Some specimens from each batch were then embrittled at 525°C. for 4 hours.

(3) *Antimony-containing En 23 (with or without Mo):* oil-quenched after 1 hour at 900°C., tempered at 620°C. (650°C for steels containing molybdenum) for 2 hours. Half of each batch was then heated for 4 hours at 525°C.

Mechanical properties were determined on all the steels, and notch-impact tests were carried out over a range of temperatures, to determine the transition temperature.

After a report of the test results, the authors discuss the mechanical implications of temper-brittleness, and the effect of embrittlement on low-temperature tensile brittleness. Conclusions are summarized below:

'Temper-brittleness can be regarded as a manifestation of the lowering of the grain-boundary brittle strength. Arsenic slightly, and antimony greatly, increase the susceptibility of nickel-chromium steels; they also raise the transition temperatures of these steels in the absence of temper-brittleness.

'The low-temperature tensile properties can show marked changes due to temper-embrittlement, but these changes are only slight in some circumstances, depending on the precise composition and heat-treatment. When embrittlement is sufficiently severe, the room-temperature tensile properties are impaired.

'Arsenic has little influence on the normal tensile properties, but antimony lowers the ductility, because it makes the steel so prone to temper-brittleness.

'Increasing the time of tempering at 625°C. produces progressive decrease in susceptibility to temper-brittleness.

'The degree of grain-boundary etching is associated with the banding present in the steels studied. It is concluded that phosphorus, arsenic and antimony are closely associated with the etching and the brittleness.

'It is suggested, in support of earlier findings, that temper-brittleness is due to the segregation of solute atoms to the grain boundaries while the steel is austenitic. These segregations are retained to a greater or lesser extent when the steel cools to room temperature. Subsequent heat-treatment in the range 300°-600°C. leads to changes in the grain-boundary structure which result in the brittleness. The nature of the grain-boundary material is not known. It is suggested that some attempt should be made to identify specifically the grain-boundary elements.'

Influence of Boron on Properties of Low-Alloy Steels

R. WILCOCK: 'Effect of Boron on the Mechanical Properties of Low-Alloy Steels.'
Jnl. Iron and Steel Inst., 1953, vol. 173, Apr., pp. 406-19. See also *Iron and Steel*, 1953, vol. 26, May 14, pp. 215-18, 228; disc., pp. 277-83.

In the development, in U.S.A., of boron-treated low-alloy heat-treatable steels, suitability for various applications has been assessed almost entirely according to hardenability, as evaluated by the Jominy test, and usually the substitution of boron-treated for other types of steel has been on the basis of roughly equal hardenability in the section under consideration. Published data on these steels give little information on mechanical properties in various ruling sections, as required by British designers.

In order to provide this type of data, tests were made by the author on steels of the compositions shown below:—

Type of Steel	C %	Mn %	Ni %	Cr %	Mo %
En 15	0·35	1·45	—	—	—
	0·35	1·45	—	—	0·10
	0·35	1·45	—	—	0·20
En 16	0·35	1·45	—	—	0·28
N.E. 8640 .. (modified)	0·40	0·90	0·55	0·40	0·12

The N.E. 8640 steel is representative of the low-molybdenum multiple-alloy boron-treated steels being used in America as substitutes for more highly alloyed compositions.

Tensile and impact tests were made on these steels, in the hardened and tempered condition, in a range of sizes up to 4 in. square, and their hardenability was investigated by means of Jominy end-quench tests and hardness traverses. From the results obtained, an

attempt is made to assess the extent to which conservation of alloy elements can usefully be effected by boron treatment of steels to typical British specifications.

It is concluded that—

'In all the steels tested, boron increased the hardenability as shown by Jominy end-quench tests and hardness traverses.

'With steels hardened and tempered between 500° and 600°C. the effect of boron on the mechanical properties varies with size at the time of heat-treatment. Each steel can be divided into three size groups, the limits of which vary from steel to steel:

(*a*) In small sizes, in which both boron-free and boron-treated steels harden fully, boron has no effect.

(*b*) In intermediate sizes, in which the boron-free steel does not harden fully but the boron-treated steel does, the boron-free steel has to be tempered at a lower temperature than the boron-treated steel to give equal mechanical properties.

(*c*) In large sizes, in which neither the boron-free nor the boron-treated steels harden fully, tensile properties are similar, but the impact values obtainable on the boron steels are inferior, usually very much so, to those on the boron-free steel.

'In certain sizes the addition of boron makes it possible to achieve a tensile strength unobtainable in the same steel without boron, except by tempering at temperatures lower than those usually considered suitable.

'The possibility of conserving alloy metals in the compositions studied, by the use of boron, when tensile and impact tests are specified, is confined to the intermediate-size group.

'On the basis of specifications En 15, En 16 and En 17, the molybdenum saved by the use of boron in 1½ per cent. manganese steels containing molybdenum varied from nil to about 0·2 per cent., depending on size.

'In small sizes tempered at 400°C. or below, boron improves the impact values, and, to a less extent, the ductility as indicated by elongation and reduction in area.

'Both boron-free and boron-treated steels have higher yield ratios when fully hardened than when partially hardened. Boron imparts no advantage in this respect, except that, by virtue of increased hardenability, good yield ratios are achieved in larger sizes than if boron were not present.'

Influence of Composition on Mechanical Properties of Cast Steel

H. JURETZEK, A. KRISCH and W. TROMMER: 'Influence of Alloy Constituents on the Mechanical Properties of Heat-Treated Steel Castings.' *Archiv für das Eisenhüttenwesen*, 1953, vol. 24, Jan.-Feb., pp. 69-82.

This is a highly detailed report of the examination of specimens from 283 experimental casts of steels, the compositions of which were adjusted to permit assessment of the influence of alloy elements, used singly, or in combinations producing binary, ternary and quaternary low-alloy varieties. The types represented are shown below:—

Steels containing one alloy element—
chromium, manganese, nickel, molybdenum.

Steels containing two alloy elements—
chromium-manganese, -nickel, -molybdenum, -vanadium, -copper.
manganese-nickel, -molybdenum, -vanadium, -copper.
nickel-molybdenum, -vanadium, -copper.
molybdenum-vanadium, -copper.

Steels containing three alloy elements—
chromium-manganese-nickel, -molybdenum, -vanadium, -copper.
chromium-nickel-molybdenum, -vanadium, -copper.
chromium-molybdenum-vanadium, -copper.
manganese-nickel-molybdenum, -vanadium, -copper.
manganese-molybdenum-vanadium, -copper.
nickel-molybdenum-vanadium, -copper.
molybdenum-vanadium-copper.

Steels containing four alloy elements.
chromium-manganese-molybdenum-vanadium.
chromium-nickel-molybdenum-vanadium.

Four test bars from each cast were water-quenched from a temperature at least 30°C. above the Ac_3 point, and were subsequently tempered to give two levels of tensile strength: 110-130 kg./mm² (70-82·5 tons per sq. in.), and 90-110 kg./mm² (57-70 tons per sq. in.). Tensile tests were made on the steels, in both conditions, at room temperature, and notched-bar impact tests were carried out at room temperature and at −50°C. In most of the steels the higher level of tensile strength could be achieved, or would have been attainable with only slight modification of heat-treatment. Yield ratios of the order of 80 per cent. were obtained.

From the point of view of toughness as determined by notched-bar impact values, the more complex steels (containing three or four alloy elements) were not in most cases superior to the binary alloy types. It is therefore concluded that, unless considerations of hardenability, castability, or other special requirement are involved, multiple alloying is not justified. The data on which these conclusions are based include detailed tables showing, for the individual steels, the temperatures of the Ac_1 and Ac_3 temperatures, hardness after water-quenching followed by tempering at various temperatures, tensile strength, elongation, and notched-impact values.

HEAT- AND CORROSION-RESISTING ALLOYS

Constitution of Iron-Nickel-Molybdenum and Cobalt-Iron-Molybdenum Alloys

D. K. DAS and P. A. BECK: 'Survey of Portions of the Iron-Nickel-Molybdenum and Cobalt-Iron-Molybdenum Ternary Systems at 1200°C.' *Nat. Advisory Committee for Aeronautics*, Tech. Note 2896, Feb., 1953; 56 pp.

This report is the last of four covering research work conducted at the University of Notre Dame under the sponsorship of the National Advisory Committee for Aeronautics, on phase diagrams of ternary and quaternary systems which are of interest in connexion

with high-temperature alloys. Previous reports have dealt with the chromium-cobalt-nickel, chromium-cobalt-nickel-iron, and chromium-cobalt-nickel-molybdenum systems (see *N.A.C.A. Tech. Notes* 2602, 2603 and 2683, respectively; *Nickel Bulletin*, 1952, vol. 25, Nos. 6 and 10, pp. 158, 159, 239).

The main purpose of the work was to provide a survey of the phase relationships in these systems, and in order to complete such a survey within practicable periods of time, it was decided to do all work at a single temperature, providing supplementary data at other temperatures only where it was required for a particular purpose. The temperature of 1200°C. was chosen for the isothermal survey work, as being within the range of technologically useful annealing temperatures, and as being high enough to allow a reasonable approach to equilibrium conditions in most alloys within one or two days, thus making possible coverage of a wide composition range, by processing a large number of alloys.

Since in the work on the iron-cobalt-molybdenum and iron-nickel-molybdenum alloys, as in the other series, the main object was to provide background information useful for high-temperature alloy development, particular attention was devoted to the face-centred cubic solid solutions present. In addition, the boundaries of all phases directly adjacent to the face-centred cubic phase, and capable of co-existing with it, were investigated. In accordance with the nomenclature used in the previous reports, the face-centred cubic phase was designated *alpha* and the body-centred cubic phase *epsilon*. The intermediate phases covered in this investigation are the following: *delta*, based on the molybdenum-nickel binary phase at approximately 36-39 per cent. nickel, the *mu* phase based on the binary intermediate phase in the iron-molybdenum system at about 55 per cent. molybdenum (and also occurring in the molybdenum-cobalt system at about 39-46 per cent. cobalt), and the *P* phase in the iron-molybdenum-nickel system. Some investigators have referred to the mu phase in the iron-molybdenum and cobalt-molybdenum systems as epsilon, but in the studies made at Notre Dame the designation mu was adopted, to avoid confusion with the body-centred cubic phase based on chromium, which occurred also in the systems covered by earlier parts of the investigation (see above). The composition of the iron-molybdenum mu phase was about 43-47 per cent. iron. The P phase was first discovered as a ternary phase in the 1200°C. isothermal section of the chromium-nickel-molybdenum system: it is not known to exist in any of the binary systems involved. For reference to the existence of a ternary phase of the same structure in the iron-nickel-molybdenum system, see below.

Conclusions drawn with regard to the iron-nickel-molybdenum system are summarized as follows:—

'The 1200°C. isothermal section of the system was investigated up to 64·5 per cent. molybdenum, by means of X-ray diffraction and microscopic methods, using 105 vacuum-melted alloys. The face-centred cubic alpha-phase field, based on austenitic iron-nickel binary solid solutions, takes into solution up to 35·5 per cent. of molybdenum near the nickel corner. The solubility of molybdenum decreases to 2 per cent. near the iron corner. In this area the austenite transforms into ferrite upon quenching from 1200°C. to room temperature.

'The body-centred cubic epsilon phase, based on binary iron-molybdenum ferrite, occupies a triangular field to the corner approximately corresponding to 8 per cent. nickel and 21 per cent. molybdenum. The mu phase field extends, in the form of a narrow strip, roughly parallel to the iron-nickel side of the diagram, up to 19·4 per cent. nickel. The delta field, based on the nickel-molybdenum intermediate phase, extends to 8·5 per cent. iron. Between these two phases the ternary P phase occupies a small range of compositions. The three phases mu, P, and delta, occupy a narrow strip, only slightly inclined with respect to the iron-nickel side of the diagram. The following three-phase fields exist: (1) alpha, epsilon, and mu; (2) alpha, mu, and P, and (3) alpha, P, and delta. The two-phase fields in the portion of the diagram investigated are: (*a*) alpha and epsilon, (*b*) alpha and mu, (*c*) mu and epsilon, (*d*) alpha and P, (*e*) mu and P, (*f*) delta and alpha, and (*g*) P and delta.'

Ferrite and Sigma in Austenitic Steels: Formation and Properties

H. BUCHHOLTZ, H. KRÄCHTER and F. KRAEMER: 'Formation of Delta Iron (Ferrite) and Sigma Phase in Austenitic Chromium-Nickel Steels, and the Properties of the Two Phases.' *Archiv für das Eisenhüttenwesen*, 1953, vol. 24, Mar.-Apr., pp. 113-24; disc., pp. 124-5.

Following a review of the pertinent literature and a consideration of some anomalous results still requiring clarification, the authors describe experimental work on 18-8 and 18-8-Mo types of steel (of German production), planned to determine the conditions in which delta iron and sigma are formed, and the interrelationships between the two phases. Metallographic methods were supplemented by examination of the magnetic properties of the steels in various conditions, and the embrittlement induced by the presence of sigma was assessed by hardness determinations and notched-bar impact tests. (The magnetic apparatus used is described and illustrated.) The compositions of the steels used in most of the experiments are shown in the Table on p. 101.

Ferrite formation was studied, as a function of temperature of treatment, in specimens of these steels which had been heated within the range 1000°-1350°C. for two hours, and subsequently water-quenched. Additional tests were made to clarify the effects of niobium+tantalum contents in excess of those required for stabilization.

In the second part of the investigation specimens of the steels were re-heated (after quenching from 1300°C.) at temperatures between 400° and 1300°C., varying by intervals of 100°C. The formation of sigma as a function of temperature, the mechanism of its formation, the influence of cold working on susceptibility to sigma formation on heating, and the conditions producing (*a*) formation of sigma from delta,

C %	Si %	Mn %	Cr %	Mo %	Ni %	Nb+Ta %	Ti %	W %
0·06	0·49	0·32	18·8	—	9·4	—	—	—
0·10	0·92	0·36	18·0	—	9·1	—	0·59	—
0·07	0·85	0·41	18·0	—	9·5	—	—	0·83
0·06	1·10	0·27	18·6	1·79	10·5	—	0·64	—
0·11	1·49	0·35	19·6	1·96	11·7	—	0·42	—
0·09	1·01	0·28	17·3	2·85	10·6	—	0·55	—
0·07	0·39	0·47	18·0	2·32	10·8	1·12	—	—
0·12	0·39	0·44	18·0	1·35	10·6	1·18	0·11	—
0·08	0·37	1·46	16·2	2·20	13·2	0·82	—	—

and (*b*) reversion to delta iron, were studied in considerable detail. Many experimental data are recorded on the individual steels and are correlated with the observations on the delta-ferrite content of the steels, recorded in the earlier part of the research.

From the results of their work the authors conclude that the usual 18-8 types of steel are not, under normal conditions, subject to precipitation of ferrite. It is, however, desirable that stabilizing elements such as titanium or niobium+tantalum should not be present in excess of the amounts serving to combine the carbon. Excess titanium has a more potent ferrite-forming effect than has niobium+tantalum. Molybdenum also tends to encourage formation of ferrite, and in steels containing molybdenum of the order of 1-2 per cent. this tendency should always be recognized. The influence of molybdenum, even up to about 2·5 per cent., can, however, be inhibited by lowering the chromium content and raising the nickel, thus reducing the chromium: nickel ratio. In some cases simultaneous increase in the manganese content is desirable.

The delta-iron/austenite transition is reversible in steels containing chromium 18, molybdenum 2, nickel 10 per cent., as well as in the straight 18-8 chromium-nickel type, although in the molybdenum-containing grade reversion of ferrite to austenite takes place much more slowly than formation of ferrite from austenite.

The investigations of sigma formation confirmed findings already published that in heterogeneous (two-phase) iron-chromium-nickel alloys the ferritic constituent is capable of transforming partially or totally into sigma. Transformation of delta iron into sigma can be produced by reheating alloys previously quenched from high temperatures. Formation of sigma begins to take place, though slowly, at about 500°C.: above 900°C. sigma begins to revert to delta iron. During furnace cooling from high temperatures delta iron transforms to sigma phase just below 900°C., i.e., the transformation is a reversible one. It was found, however, that the delta phase did not totally transform to sigma, but the structure of the transformed material showed a small amount of a phase which is believed to be a newly formed austenite.

Examination of the mechanical properties of the steels confirmed observations made by other investigators, with regard to the increase in hardness and brittleness associated with formation of sigma. This brittleness was found to be evident not only at room temperature, but also at the tempering temperature which had produced the transformation to sigma.

In the main series of steels studied by these authors sigma-phase formation was investigated only as a product resulting from transformation of delta iron. In view of findings reported by other workers that sigma phase may be formed direct from austenitic or carbidic phases, supplementary tests were made on a steel containing chromium 25, nickel 20, per cent. The results indicate that, after relatively long periods of heating, sigma phase can co-exist with chromium carbide.

X-ray examination indicated that sigma phase has a tetragonal lattice with the axis ratio c/a=1·46 and a lattice constant a = 6·26Å.

Study of specimens which had been cold worked before heating showed that in fully austenitic steels mechanical deformation had no influence on sigma formation when the material was subsequently heated for periods up to 24 hours. In austenitic steels containing some ferrite, however, cold working prior to heating favoured formation of sigma.

High-Temperature Materials: Fabrication Problems

H. BROWN: 'How to Solve Fabricating Problems of High-Temperature Alloys.' *Iron Age*, 1953, vol. 171, Apr. 16, pp. 121-5.

This article is an essentially practical discussion of some of the difficulties likely to arise in fabricating high-alloy materials of the types used for gas-turbine parts and other components. A table shows the compositions of over 30 typical materials, classified in groups according to their generic character. The designations used are those of American makers and standardizing bodies, but the types represented are in many cases closely similar to alloys used in U.K.

The article consists of a concise discussion, seriatim, of the following aspects of fabrication of some or all of these materials:—

(1) Influence of speed of pulling, in the tensile test,

on elongation values: variation of this effect with thickness of material tested and with type of test piece.

(2) Importance of avoiding work-hardening, in preparation of test specimens to be used in determination of ductility.

(3) Importance of grain-size control: occurrence of orange-peel and other defects in coarse-grained alloys.

(4) Difficulty of forming material in which a chromium-carbide network is present.

(5) Factors affecting weldability, and variation of welding properties, from heat to heat, in materials of nominally identical composition. Importance of specifying silicon range in austenitic steels to be welded: 0·5-1·0 per cent. preferred.

(6) Contamination liable to occur from high carbon in the weld area: avoidance of contact with carbon- or zinc-containing objects, such as marking pencils, identification tags, galvanized holding trays, etc.

(7) Occurrence of hot-shortness in some of the high-alloy materials, e.g., N.-155 (complex nickel-chromium-cobalt-iron alloy); consideration of this feature in relation to hot-working temperatures, and welding technique.

(8) Precautions necessary in welding age-hardened materials, e.g., of Inconel and similar types; importance of control of cooling conditions after annealing or stress-relief treatment of welded parts.

(9) Methods of stacking for heat-treatment; avoidance of piling which prevents circulation of heat or retards cooling; importance of free air circulation in preventing attack by molybdenum oxide.

(10) Nature of scale formed on the alloys in (*a*) reducing, or (*b*) oxidizing atmospheres. Possibility of utilizing the light, tight scale formed in reducing atmospheres, as a 'lubricant' and as a protective coating; means for removal of the loose scale formed in oxidizing atmospheres, by pickling, blasting or grinding.

All sections of the paper are illustrated by examples of typical parts showing the characteristics discussed.

N.A. 22H Alloy: Properties and Uses

M. N. ORNITZ and R. H. ENGLISH: 'A New High-Temperature Alloy.' *Iron and Steel Engineer*, 1953, vol. 30, Feb., pp. 102-12; disc., pp. 112-17.

This paper gives a detailed account of research carried out to develop an alloy which (*a*) could be used at temperatures above 2000°F. (1095°C.), (*b*) would retain sufficient strength to have practical engineering application at 2200°F. (1205°C.), and (*c*) would have sufficiently good resistance to oxidation to give a satisfactory operating life at that temperature.

Early in the investigation it became apparent that at the temperatures under consideration it was necessary to strengthen the solid-solution matrix of the alloy in combination with the formation of stable complex carbides, rather than strengthening by formation of a precipitate. It was also found that unless the chemical balance of composition achieved was such as to ensure formation of a tight adherent oxide scale, the addition of such elements as molybdenum and vanadium, and of chromium and tungsten within certain ranges, resulted in a porous oxide which tended to accelerate oxidation of the alloy.

A description is given of a cantilever creep test method which was used for initial evaluation of the potential usefulness of the many compositions tried, and of equipment devised for high-temperature tensile and creep-rupture testing, and for determination of resistance to thermal shock.

The limits of composition developed, by these and other tests, as optimum, are covered by U.S. Patent 2,540,107. They are as follows: nickel 40-60, tungsten 4-6·5, chromium 22-34, carbon 0·35-0·75, per cent., balance substantially iron.

This paper gives much detailed information on the properties of alloys within that range, comparing them with those of 35-15, 12-25, 65-15, and 20-25 nickel-chromium-iron alloys. Creep and stress-rupture characteristics are illustrated, extensive data on results obtained in the cantilever creep tests are presented, and the oxidation-resistance of N.A. 22H, in comparison with that of the other alloys, is reported, as determined in constant-temperature and cycling tests, and in various atmospheres. The alloy is stated to have excellent welding qualities, and its resistance to thermal fatigue is believed to be equal to that of other commercial alloys of comparable type.

The laboratory test data detailed in the paper are supplemented by records of case histories demonstrating the behaviour and life of N.A. 22H alloy parts under service conditions. Examples include radiant tube assemblies operating at an average temperature of 2000°F. (1095°C.); retorts for endothermic gas generators (where the introduction of N.A. 22H has permitted use of higher temperatures and increased output), and a variety of furnace parts and other components working at high temperatures.

Passivation of Nickel-Chromium Stainless Steel in Sulphuric Acid by Potassium Dichromate

I. D. G. BERWICK: 'The Influence of Potassium Dichromate on Stainless Steel in De-aerated Sulphuric Acid.' *Chemistry and Industry*, 1953, Apr. 25, pp. 408-9.

This brief note reports studies which have established that, in the complete absence of oxygen, potassium dichromate passivates 18-8 chromium-nickel steel in sulphuric acid, provided that the dichromate exceeds a certain concentration. In 0·5-*M* acid at 20°C. the minimal concentration required to produce passivity corresponds to 1300 parts per million of dichromate. The minimal concentration required to secure passivation increases with the concentration of the acid and its temperature.

The mechanism of the inhibiting action of potassium dichromate is briefly discussed; it is reported that experiments made by the author suggest that the dichromate behaves in the same manner as oxygen: inhibition is believed to involve a direct oxidation of the surface of the stainless steel. The relevant experiments are to be reported fully at a later date.

Nickel-containing Materials in Non-Magnetic Ships

L. G. STEVENS: 'Non-Magnetic Ship: the U.S.S. 'Illusive'.' *Welding Engineer*, 1953, vol. 38, Feb., pp. 23-5.

This article has been written in connexion with the launching of the wooden-hulled minesweeper 'Illusive', designed to be immune from susceptibility to magnetic mines.

Certain parts of the equipment of the ship called for metallic materials, and, on account of the non-magnetic character of austenitic chromium-nickel stainless steel, extensive use has been made of this type of material, e.g., for engine mounts, tanks, etc. Powder cutting has been employed for shaping many of the sections of stainless steel for the tanks, which are of welded construction. Dry compressed air is the vehicle normally used for conveying the powder from the dispenser hopper to the cutting tip, but in this case nitrogen and 'Nyrogen' gas have been used. The latter is a non-combustible gas mixture specially developed for this purpose: its use is claimed to promote maximum flaking of slag, ensuring clean, accurate cuts which require a minimum of cleaning. Monel has been used for some of the fresh-water tanks on the 'Illusive'.

Identification of Alloys and Stainless Steels

G. C. CLARK and E. E. HALE: 'The Identification of Alloys and Stainless Steels by Electrographic Methods.' *Analyst*, 1953, vol. 78, Mar., pp. 145-7; disc., pp. 167-8.

The authors describe a method for the identification of various grades of stainless steel, nickel-copper alloys and nickel-chromium-iron alloys of the types used in construction of chemical plant. An electrographic method, which obviates drilling or cutting, is used for testing; the constituents on the electrogram are identified by a series of spot tests systematically applied to classify the type of material under examination. Particulars are given of procedure to be used for detection of copper, nickel, iron, molybdenum, titanium, chromium. In discussion it emerged that tungsten also could be detected by electrographic methods, but that no satisfactory identification of niobium or tantalum had yet been achieved by this technique.

Addendum

Nickel Bulletin, April 1953, p. 70, 'Bright Nickel Plating Baths'— add '*U.S. Pat.* 2615837'.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks.*

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